Brief Papers

Smart, Active, and Concealable Antenna Array for Portable Television Reception

Oded Bendov

Abstract—**This paper describes an array which is concealable with a TV set or set-top box. The array is made of small active antennas which can provide space and polarization diversity by phase switching alone. The array can be manually or automatically controlled to maximize the signal-noise ratio of the desired channel and minimize the interference from undesired channels. The combination of automatically adjustable dual diversity and small physical size makes this device suitable for mobile reception.**

***Index Terms*—Active antenna, array, polarization diversity, space diversity.**

I. Introduction

CONVENTIONAL television reception requires an outdoor rooftop or an indoor set-top antenna. This tethered arrangement is unsightly and limits the flexibility of the viewer to move the set about. Some residential communities do not permit installation of rooftop antennas. For analog TV received with typical indoor antennas such as loops, monopoles and "rabbit-ears" the picture quality is usually very poor. For digital television [DTV], which is expected to be the future of wireless television worldwide, reliable reception in urban and suburban locations with typical indoor antennas has been problematic.

Earlier attempts at designing small and concealed antennas for television reception without loss of performance relative to outdoor antennas have failed [1]–[3]. The earlier designs did not focus on two critical areas of system design. One area that earlier designers have failed to appreciate is the importance of matching, over the television bandwidth, the antenna's input impedance to the television conjugate input impedance of the receiver' front-end at the front-end's point of minimum noise figure. Another area that earlier designers have not appreciated is the importance of providing an antenna array capable of controlled polarization diversity and space diversity reception by automatically switching individual radiators within the array automatically or manually to attain optimum reception regardless of the physical location of the TV set. To be concealable within the TV set or within a set-top box, a switched array must be made of small, active and broadband antennas designed to minimize the noise figure of the receiver at all TV channels. The switching of the various active antennas must be such as to provide a multitude of array patterns with variable polarization that would discriminate against undesired channels and allow for the reception of the desired channel independent of the physical location of the TV set.

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TABLE I
FCC Planning Factors for Rooftop Antennas

Antenna Impedance	75 ohms
Channel Bandwidth	6 MHz
Thermal Noise (dBu)	2.6 (+)
Dipole Factor (dB)	-22 (-)
Noise Figure (dB)	10 (+)
CNR (dB)	28.4 (+)
Rooftop Antenna Directivity (dB)	13 (-)
Line Loss (dB)	5 (+)
Margin for 90% time availability (dB)	9 (+)
Required Field Strength (dBu) 30' AG	64

TABLE II
City Grade Planning Factors for Indoor Antennas

Antenna Impedance	75 ohms
Channel Bandwidth	6 MHz
Thermal Noise (dBu)	2.6 (+)
Dipole Factor (dB)	-22 (-)
Noise Figure (dB)	2 (+)
CNR (dB)	28.4 (+)
Indoor Antenna Directivity (dB)	.8 (-)
Impedance Mismatch Loss (dB)	.8 (+)
Height and Building Penetration Loss (dB)	9 (+)
Required Field Strength (dBu)	64

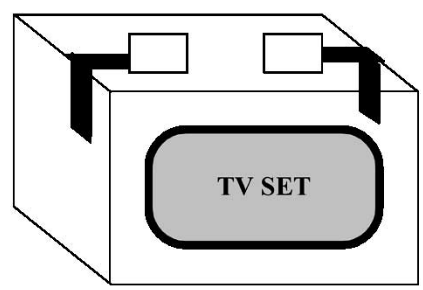

Fig. 1. Array of Two Active Antennas.

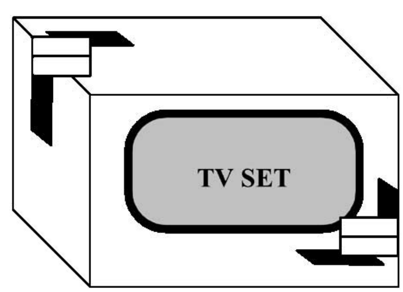

Fig. 2. Array of Four Active Antennas.

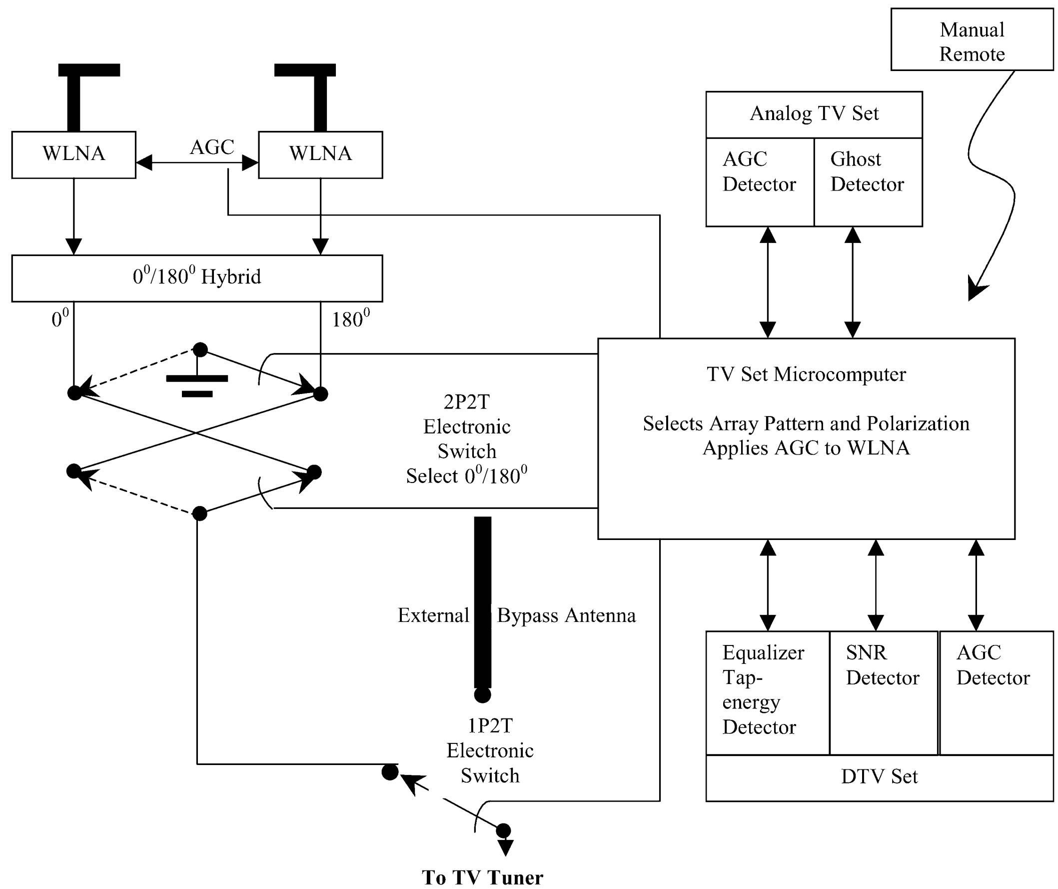

Fig. 3. High-Speed Signal processor of Array of Two Active Antennas.

II. Overview

The proposed antenna is an array of active antennas in which each antenna can be small, being an integral part of a wide-band low-noise amplifier [WLNA]. Because each active antenna is small, an array of several active antennas can be embedded within a television set with screen diagonal of at least 13". The availability of several antennas allows the array to provide electronically controlled space and polarization diversity as well as pattern steering for improved reception of the desired analog TV and DTV signals and rejection of the undesired signals. Such an array could replace unsightly set-top or outdoor antennas while maintaining comparable efficiency.

Each of the active antennas within the array has a directivity lower than that of a typical outdoor antenna. Prior to being integrated with the WLNA, each antenna may also have a lower input resistance, which would make efficient transfer of all the energy of the intercepted signals to the television set difficult. The loss of directivity relative to an outdoor antenna is more than made up for by the WLNA whose noise figure, when integrated with the antenna, would be much lower than that of a typical TV set. By further designing the WLNA to provide a conjugate impedance match to the antenna's input impedance, the received signal would be transferred to the television set with little loss of strength.

Table I shows the planning factors as established by the U.S. Federal Communications Commission [FCC] for reception of analog television in the UHF band at the edge of coverage [Grade B].

From this table it is clear that if the noise figure of the receiver could be lowered to 2 dB, the antenna gain of 8 dB ($+13$ dB directivity -5 dB line loss) could be reduced to 0 dB and the required field intensity of 64 dBu would not be breached. Table I is based on an idealized antenna whose impedance is matched to that of the downlead cable. In reality, the antenna impedance is mismatched to that of the downlead cable and that mismatch causes a substantial increase of the in situ noise figure of the TV set. There is no upper limit to the increase of the noise figure with increased impedance, but a reasonable estimate for the in situ noise figure, depending on antenna and channel, could easily be 12–15 dB [4], thereby actually providing a greater opportunity for trading gain for lower noise figure.

The directivity of a short monopole antenna is similar to that of a half-wave dipole antenna. For example, a monopole antenna whose length may be only 1/4 that of a half-wave dipole antenna has a directivity only -0.4 dB lower than that of the half-wave dipole antenna.

If the array were constructed from half-wave dipoles, its average directivity would be 1.2 dB. Since it is intended for the array to be constructed from short linear antennas, its estimated directivity would be $1.2 - .4 = .8$ dB. The revised planning factors for indoor analog television reception using the proposed array are shown in Table II.

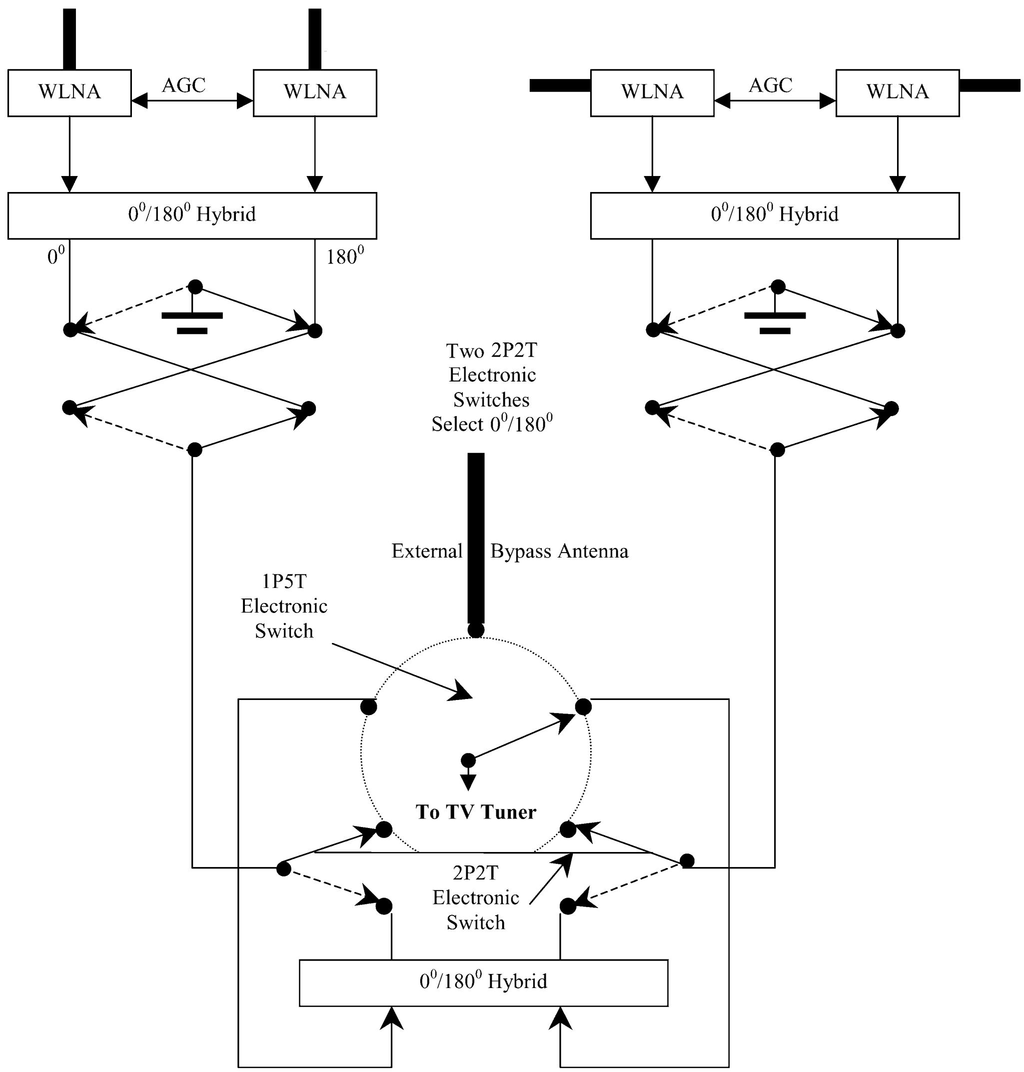

Fig. 4. High-Speed Signal processor of Array of Four Active Antennas.

In Table II, Line Loss has been replaced by Impedance Mismatch Loss because the antenna is an integral part of the WLNA and there is no cable separating the two. Also, the margin for 90% time availability is not required within the licensed City Grade. Therefore, in Table II, the margin for 90% time availability was replaced with a margin for the loss due to the antenna's lower height above ground and the loss due to building penetration. The 9 dB loss is augmented by the fact that the City Grade contour typically extends to 35 miles from the transmitter whereas Grade B, the edge of reception, typically extends to 50 miles from the transmitter. The difference of 14 miles translates to an additional margin of at least 14 dB, for a total of 23 dB loss due to height and building penetration within the City Grade. Therefore, reception within the City Grade contour using the proposed array would be feasible even with significant loss due to building penetration and height less than 30 feet above ground for the receive antenna.

The main obstacle to using a short monopole antenna to replace a much larger antenna is the difficulty in devising circuits that would allow the power received at the antenna to be delivered to the receiver without substantial reflection of power back to the antenna. That obstacle can be ameliorated by properly integrating the short antenna with the WLNA into a single device.

The input impedance of a short monopole can be approximated as:

$$Z = 10\left(\frac{2\pi l}{\lambda}\right)^2 - j\frac{Z_A}{\tan(2\pi l/\lambda)}$$

where Z_A is the characteristic impedance of the antenna, l is the length of the antenna and λ is the operating wavelength.

For a monopole, the characteristic impedance is given by:

$$Z_A = 60\ln\left(1.15\frac{l}{d}\right)$$

where d is the diameter of the monopole.

A monopole is just one option for the short antenna [5]. From the analysis of the antenna's directivity and its input impedance it should be clear that if Z, the antenna's input impedance, could be conjugate matched with the input impedance of the WLNA, the array would provide indoor television reception similar to that available using a consumer-grade outdoor antenna. In the

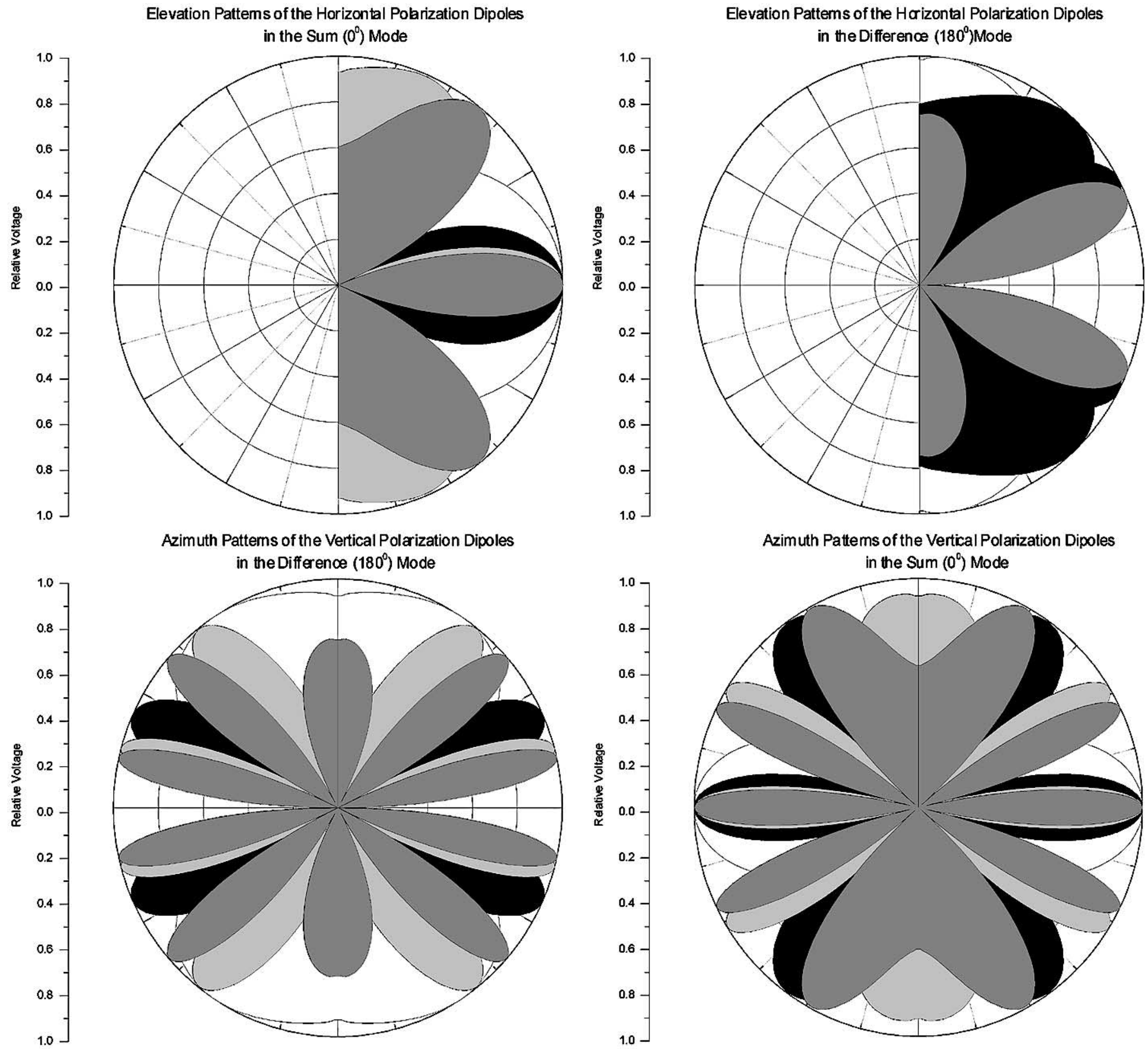

Fig. 5. Azimuth and Elevation patterns of the array of Four Active antennas in a 16 × 9 Frame. White: 13″ screen. Black: 27″ screen. Light grey: 42″ screen. Grey: 60″ screen.

next section it will be shown that the concealable array needs no physical orientation by the user and provides space and polarization diversity switching to minimize the degradation of picture quality by undesired reflections from nearby obstructions.

III. System Configuration and Principle of Operation

Fig. 1 shows a configuration of an array of two active L-shaped antennas. The array is physically either inside the TV set or on a separate frame outside the TV set. Being L-shaped, the antennas receive incident signals with horizontal or vertical polarization. The antennas are physically spaced at least one quarter wavelength apart, thereby providing space and polarization diversity for improved reception.

The integrated design ensures that the noise figure of the integrated device is at an optimum for all desired TV channels. The WLNA could be configured as either a single amplifier or as dual balanced amplifiers. The dual balanced configuration provides for an improved impedance match between the WLNA and the short antenna [6], [7].

The integrated devices of Fig. 1 are connected to a high-speed signal processor an implementation of which is shown in Fig. 3. The signal processor provides for reception pattern diversity that maximizes the level of the desired signal and minimizes the level of all undesired signals that are intercepted by the array.

The high-speed signal processor shown in Fig. 3 is made of electronic switches, a sum/difference hybrid and a microcomputer controller. One purpose of the controller is to regulate the AGC voltage to the WLNAs to minimize the amplifier overload in areas of strong signals. Overloading the amplifier may cause the WLNAs to generate undesired intermodulation products. Additional reduction in the level of intermodulation products generated by the WLNA can be accomplished by adding a variable attenuator between the passive part of the antenna and the WLNA. The effect of the added attenuation is to reduce the intermodulation products level by at least 3 dB for every 1 dB reduction in the desired signal level.

The signals received by the antennas and amplified by the WLNAs are then input to the hybrid. The hybrid processes the incoming signals into two distinct outputs. One output provides the sum vector (0°) of the two inputs and the other output provides the difference vector (180°) of the two inputs.

A double-pole, double-throw electronic switch provides two choices of array pattern. If the signal received via either array pattern is deemed by the controller to be inferior to that of an external bypass antenna, an electronic switch connects the bypass antenna to the tuner. The antenna switching and the bias voltage to the WLNAs can be controlled manually or automatically. For automatic control of digital television, several signals such as AGC (Automatic Gain Control), SNR (Signal to Noise Ratio) and ETE (and Equalizer Tap Energy) can be made available by the receiver. The electronic switches may also be controlled manually by giving the hand-held remote used to control the TV/VCR/DVD the ability to communicate with the controller. A combination of automatic and manual controls will be particularly suitable for analog television.

Another implementation of the active array concept is shown in Fig. 2. This array is more somewhat more complex, but together with the signal processor shown in Fig. 4, it is expected to provide improved reception.

Referring to Fig. 4, thirteen states are available:

1) $\mathrm{A} =$ Vector sum of the signals of vertical antennas.
2) $\mathrm{B} =$ Vector difference of the signals of the horizontal antennas.
3) $\mathrm{C} =$ Sum of the signals of vertical antennas.
4) $\mathrm{D} =$ Difference of the signals of the horizontal antennas.
5) $\mathrm{A} + \mathrm{C}$
6) $\mathrm{B} + \mathrm{D}$
7) $\mathrm{A} + \mathrm{D}$
8) $\mathrm{B} + \mathrm{C}$
9) $\mathrm{A} - \mathrm{C}$
10) $\mathrm{B} - \mathrm{D}$
11) $\mathrm{A} - \mathrm{D}$
12) $\mathrm{B} - \mathrm{C}$
13) Bypass antenna to TV tuner

The sum and difference elevation and azimuth patterns generated by the switches shown in Fig. 4 are plotted in Fig. 5. The plotted patterns in Fig. 5 show that space and polarization diversity reception is feasible for the arrays of two and four active antennas, whether concealed inside the TV set or mounted on a frame external to the TV set. In particular, Fig. 5 shows that in the difference mode a reception null is provided at elevation angle of 90° in all azimuth directions. The reception null allows for discrimination against undesired signals.

IV. Conclusion

It is possible to replace a traditional rooftop antenna by a suitably designed array of small active antennas concealable within the television set or within a set-top box, and to obtain reception indoors comparable to that available from a rooftop antenna.

The array is dynamically controlled by a simple and fast signal processor to maximize the desired signal's level and quality and minimize the interference by undesired television channels.

The physical orientation of the array, whether inside or outside the set can be arbitrary as long as the vertical elements of the array remain perpendicular to the ground and the horizontal elements of the array remain parallel to the ground.

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